BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 10096

SUBJECT: Review of Dual-Mode Lunar Roving Vehicle (DLRV) Design Definition Study - Case 320

DATE: October 29, 1969

FROM: J. C. Slaybaugh

ABSTRACT

A Phase B Design Definition Study of a Dual-Mode Lunar Roving Vehicle (DLRV) has reached its midway point. Preliminary configurations by Bendix and Grumman have been reviewed and accepted by MSFC. Bendix has proposed a 6x6 (six wheels, six motors) cart and trailer arrangement providing degraded operation using the 4x4 cart alone. Grumman has proposed a fully articulated 6x6 vehicle driven in opposite directions in the manned and unmanned modes.

Several problems remain unresolved. Both contractors are currently estimating vehicle weights in excess of design requirements. The ability of either vehicle to meet the 35° slope climbing requirement is in doubt. In addition, Bendix has based its electrical power system on a multihundred watt Radioactive Thermoelectric Generator (RTG) still in the developmental stages. The performance of the Grumman wheel, in its unmodified version, has been well below that of competitive designs.

MSFC has agreed to more fully define requirements in the areas of scientific instrumentation, Extravehicular Mobility Unit capabilities, mission timelines, night operation, and soil characteristics.

(NASA-CR-107362) REVIEW OF DUAL-MODE LUNAR ROVING VEHICLE /DLRV/ - DESIGN DEFINITICN STUDY (Bellcomm, Inc.) 14 p

N79-72014

Unclas
00/14 11673

FF No. 602(A)

(ACCESSION NUMBER) (THRU)
14 (PAGES) None (CODE)
Cr-107362 (NASA CR OR TMX OR AD NUMBER) (CATEGORY)

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MEMORANDUM FOR FILE

INTRODUCTION

A Dual-Mode (Manned/Automated) Lunar Roving Vehicle (DLRV) is being studied by the Lunar Mobility Task Team at MSFC. Under consideration for the Post-Apollo 20 time period, the vehicle would provide enhanced mobility for manned lunar missions in addition to being capable of one year's unmanned mobile scientific operation by remote control from Earth.

A midterm review of the DLRV Design Definition Study was presented October 7 through 10, 1969 at MSFC. The six-month study, suspended during July and August pending final preparation of a manned-only Lunar Roving Vehicle (LRV) study, was reactivated at the beginning of September. Bendix Aerospace Systems Division and Grumman Aircraft Engineering Corporation each participated in two days of review and critique with MSFC's Lunar Mobility Task Team. Both contractors have defined preliminary configurations and are estimating weight and performance data from those designs. Further definition of science and operational requirements by MSFC is necessary, however, before configurations and performance data is finalized.

CONFIGURATION

1. General: Figures 1 and 2 show the baseline configurations of the Bendix and Grumman vehicles, respectively. Both contractors have proposed a 6 x 6 (six wheel, six motor) vehicle, capable of stowage in two bays of the LM descent stage. The Bendix design features a four wheel forward chassis and a two wheel trailer, with Ackerman steering of the front and rear wheel pairs. The Grumman concept is a fully articulated vehicle with the front joint locked in pitch for crevasse negotiability. Bendix has optimized its design for six wheeled operation, but has also provided for degraded manned operation in a four wheel mode. Grumman has proposed a double ended configuration (driving in opposite directions manned and unmanned) to optimize arrangement of scientific equipment.

Two significant differences in the general configurations proposed by the contractors are evident. The Bendix design, with a 58", equal separation wheel base and an overall length of 148" is considerably shorter than the 96" wheel base, 230" overall length, Grumman concept. (The effect of this difference on vehicle performance is not yet clear.) In addition, Bendix has chosen to place its crew members side by side at the front of the vehicle. Grumman, assuming primarily single-astronaut operation, has placed only one crew member in the forward driving position, while making provision for a second crewman with a sling located between the front two vehicle sections.

The overall approaches taken by the two contractors seem to be slightly different. Bendix has produced a design which is essentially an extension of the manned four-wheeled LRV. Grumman, on the other hand, has produced an independent six-wheeled concept.

2. Wheels and Suspension: The wheel and suspension systems proposed by the two contractors indicate significant differences in design philosophy. The metal-elastic Bendix wheel, shown in Figure 3, is a formidable exercise in mechanical design. Due to the complex structure, the fatigue reliability for long duration missions remains in question. By comparison, Grumman's continuous structure conical wheel, shown in Figure 4, is an extremely simple design. Recent work of Waterways Experiment Station, however, raises doubt as to the performance capabilities of this wheel in its unmodified version [1]. As presented in the current studies, the Bendix wheel is 32 inches in diameter while the Grumman wheel has a 38 inch diameter. Neither wheel appears to provide the required slope climbing capability of 35° in soft soil. As a result, both contractors were directed to examine the impact of low wheel loading (0.1-0.2 psi) on performance and design of their vehicles.

Bendix proposes a coulomb damper to meet its suspension design requirements. This device, performing the same task as a hydraulic damper, offers higher reliability for the long-range unmanned missions. Grumman does not include a separate damping system, but relies on single swing arm side loading, scuff damping, and the inherent damping characteristics of its wheel to provide adequate energy dissipation.

3. Electrical Power System (EPS): Both contractors have sized their power systems for the manned mission. This requirement comes from the system weight sensitivity to battery charge time between sorties. Bendix has chosen a combined Radioactive Thermoelectric Generator (RTG)/rechargeable primary battery system. The batteries are used as primary

batteries during the manned mode, and are recharged by the RTG between sorties. Grumman has proposed a three element, RTG/ sollar array/battery system for their vehicle. The batteries and RTG supply primary power during manned sorties, while the solar array and RTG supply prime power during unmanned missions. The solar array is also used to recharge the batteries between manned sorties.

Bendix is proposing the use of a 40 lb, multihundred watt RTG currently under development, which results in a total electrical system weight of approximately 181 lbs. Grumman has used the more conservative 82 lb SNAP 19 RTG in its estimates, and has a corresponding weight estimate of 242 lbs.

4. Weight: Table 1 presents the weight estimates for each vehicle. Due to the high cost of landing payload on the moon, the DLRV weight limit of 650 lbs is one of the most important vehicle requirements. Unfortunately, both contractors are presently estimating vehicle weights of approximately 700 lbs. MSFC has directed both Bendix and Grumman to put additional emphasis during the next report period on the problem of meeting the weight requirement.

5. Astrionics: The navigation, communication and hazard detection work done by the contractors to date has been chiefly at the conceptual level. Unacceptable areas have been identified, and both contractors plan to present more detailed systems by the next monthly meeting. One of the major conclusions reached has been that astrionics functions and capabilities are strongly dependent upon system weight. In view of the problems already encountered with meeting weight requirements, it is possible that the astrionics constraints will have to be re-examined in light of overall vehicle performance.

PERFORMANCE

Preliminary data on vehicle performance indicates that, although the majority of the Statement of Work (SOW) requirements will be met by both vehicles, several criteria may prove difficult to meet. Table 2 provides a comparison of the predicted performance of each vehicle. Although Grumman has not yet determined all of its performance data, it can safely be assumed that no significant difficulty will arise in traversing a 27 inch crevasse with a 38 inch wheel. Strong doubt does exist, however, concerning either vehicle's capability to negotiate a 35° slope in soft soil. Barring any major design changes in the wheels already proposed, it does not appear that this criteria will be met. It has been shown, however, that very promising results can be obtained in this area with low wheel loading. In particular, wheel bearing pressures in the region of 0.1 to 0.2 psi have produced slope climbing capabilities approaching the angle of repose of sandy slopes on Earth [2]. To obtain such pressures, however, would require major redesign of the existing wheels, or development of a totally different wheel concept. The question of the impact of such changes on other vehicle parameters must also be investigated. Should such a change prove unacceptable, the only remaining solution would be to relax the design requirement. The feasibility of such a solution in the light of unmanned science requirements would have to be studied carefully.

The other major SOW requirement still unresolved is the break angle for unmanned operation. The geometry of this angle is shown in Figure 2. As the science payload and arrangement are yet to be determined, it seems likely that, when decisions are made in those areas, better correlation with the specifications will be provided.

It should also be noted that the Bendix vehicle does not meet the turning radius requirement of one vehicle length. No mention of this shortcoming has been made by either Bendix or MSFC.

CONCLUSIONS

1. Vehicle Weight - Both contractors are currently predicting vehicle weights well in excess of design goals. In view of past experience with delivery vehicle payload capabilities, there is no reason to anticipate room for DLRV weight growth. It would, therefore, seem essential to keep the vehicle weight within its 650 lb design goal. This should be a major target of contractor effort during the remainder of this study.

2. Performance - Neither vehicle currently meets all performance requirements. In particular, the 35° slope capability requirement appears to be a major obstacle to vehicle development. As both contractors have spent considerable time and effort during this and other studies in development and optimization of these wheel designs, it is doubtful that further significant performance improvements will be made without major changes in wheel design. Decreasing wheel loading to values of 0.1 to 0.2 psi has shown considerable promise in previous studies [2]. However, the effect of this modification on the overall DLRV design would have to be investigated.

3. Bendix RTG - The Bendix EPS weight summary relies heavily on the development of a 40 lb, multihundred watt RTG. Doubt exists as to the availability of this hardware item before the late-1973 target data for the initial DLRV flight. If, indeed, the new RTG is not available, the weight penalty associated with a SNAP 19 model would be in the neighborhood of 42 lbs. Considering the weight problems already present, this could be a severe drawback to the Bendix design.

4. Grumman Wheel - Tests at Waterways Experiment Station [1] indicate that unmodified conical wheel performance is a factor of 2 poorer than that of the Bendix wheel. Although these results were significantly improved by the addition of grousers, the impact of the modification on vehicle weight, performance and reliability should be carefully studied.

5. MSFC definition: Several areas within the study scope are yet to be fully defined by MSFC. Among the more important of these are scientific instrument requirements, Extravehicular Mobility Unit definition, mission timeline requirements (number of sorties per day, duty cycles, etc.), night operational requirements, and soil characteristics. Members of the Lunar Mobility Task Team will undertake to define these areas as soon as possible.

MSFC has accepted the preliminary configuration decisions proposed by Bendix and Grumman. It remains for the contractors to proceed with detailed design. The next study review, scheduled for mid-November, should provide a better basis for comparison of the two vehicles.

2032-JCS-mp

J. C. Slaybaugh

Attachments
Figures 1-4
Tables 1-2

References

1. Single Wheel and Vehicle Performance Data, U. S. Army Engineer Waterways Experiment Station Report, Vicksburg, Mississippi, 16 September 1969.

2. General Motors Defense Research Laboratory, Santa Barbara, California. Lunar Roving Vehicle Concept, 16 mm film, 14 min., 1968.

BENDIX CONFIGURATION

MANNED 6-WHEEL DLRV

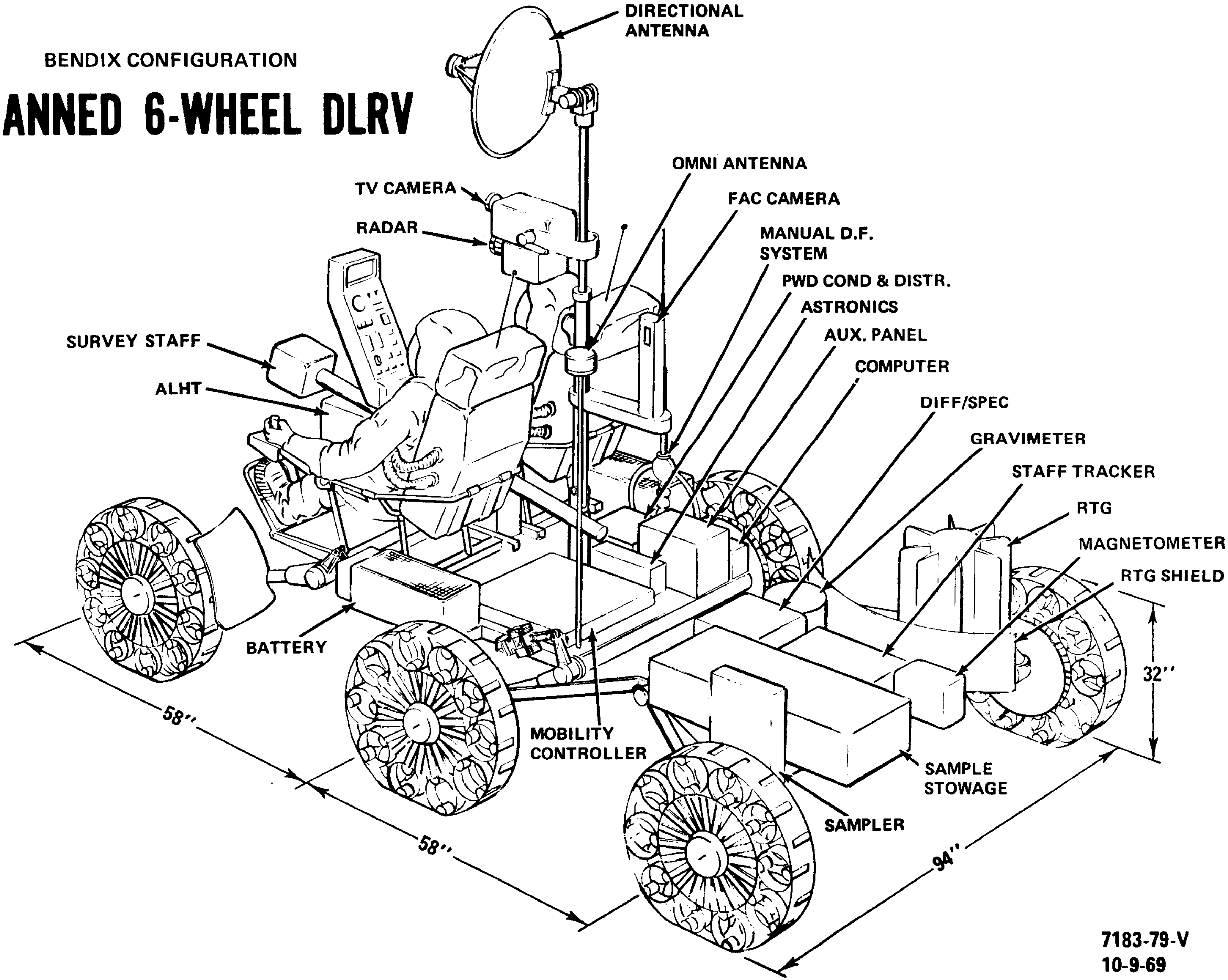

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FIGURE 1

GRUMMAN DLRV CONFIGURATION

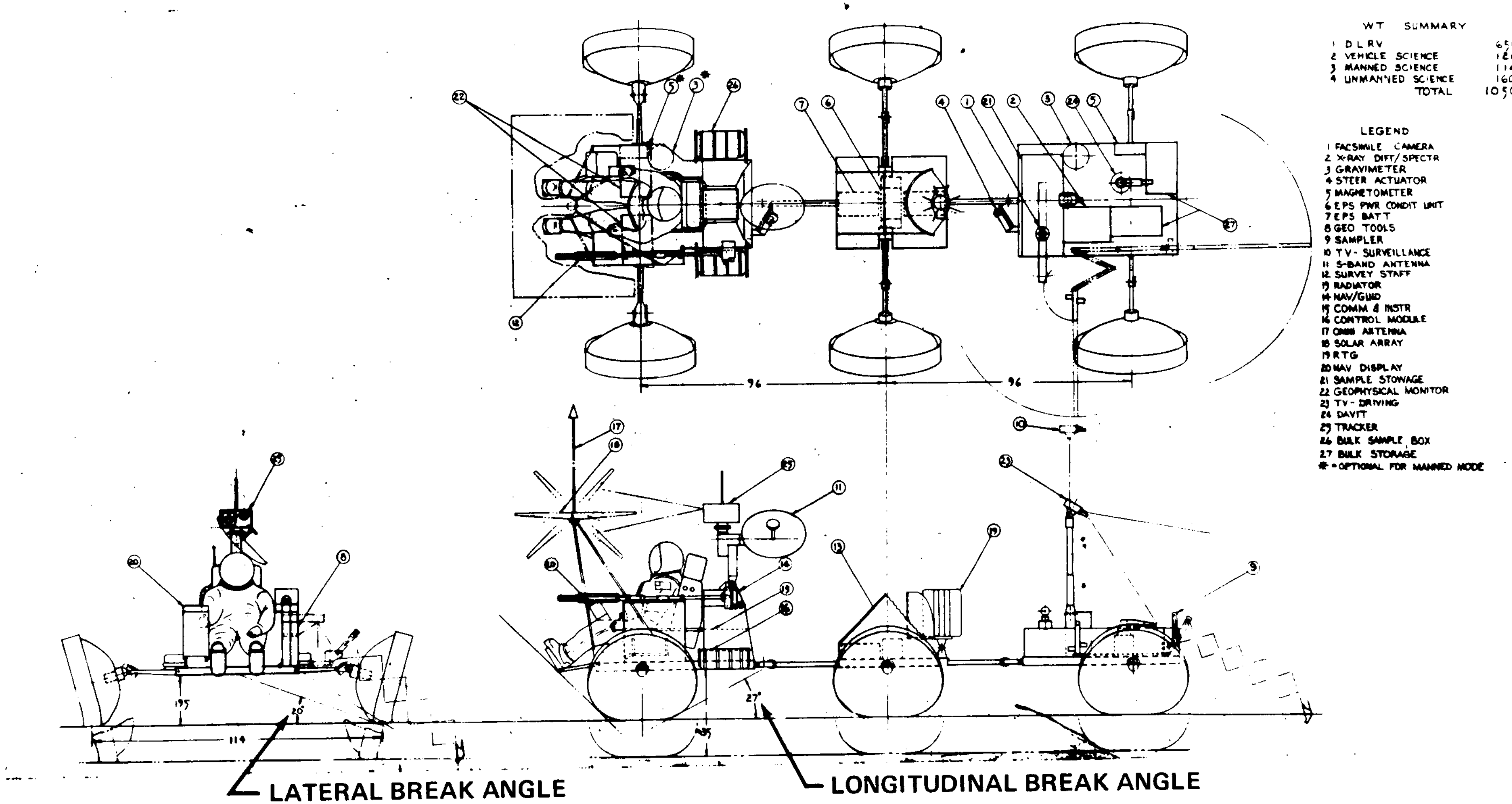
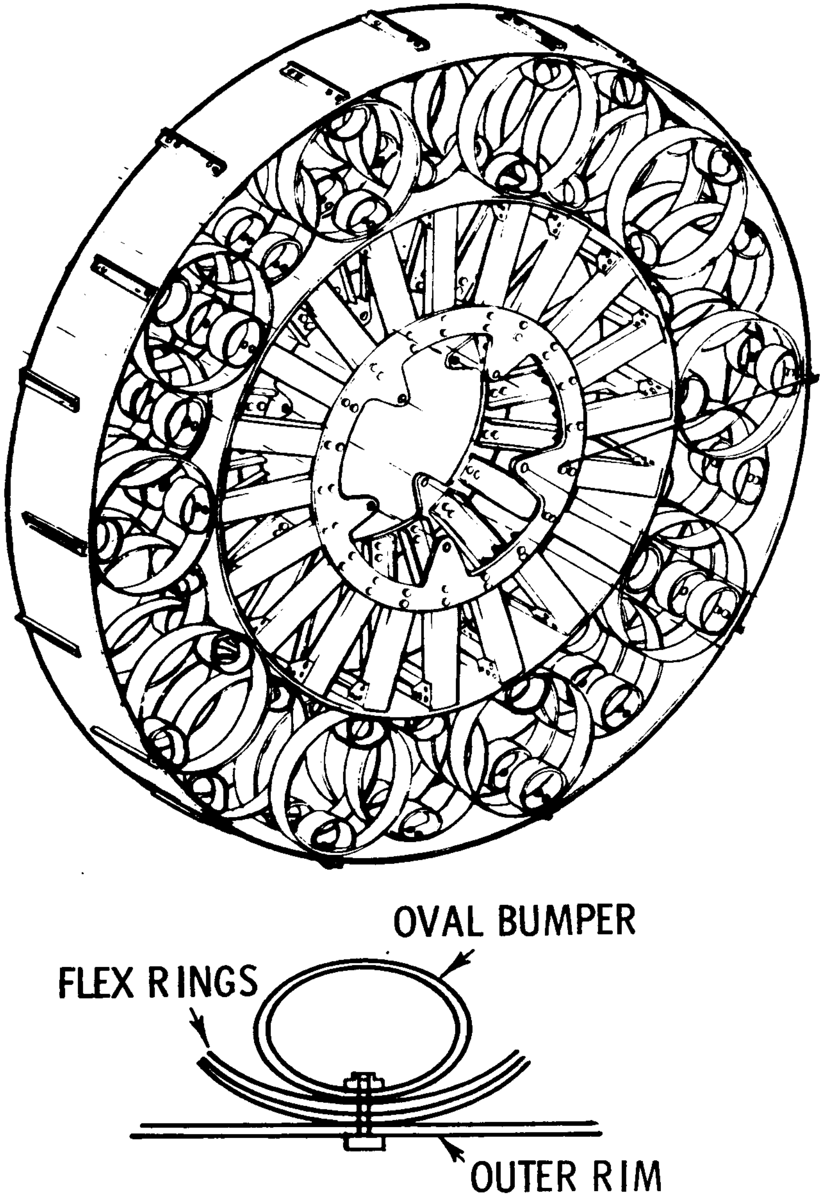


FIGURE 2

BENDIX

WHEEL DESIGN



GROUSERS:	Ti 6Al 4V ANNEALED .030 THICK
OUTER RIM:	Ti 6Al 4V ANNEALED .020 THICK
RINGS:	Ti 6Al 4V STA .016 THICK, LAMINATED DESIGN
OVAL BUMPERS:	Al 2024-T3 EXTRUSION
INNER RIM:	Al 7178-T6 .020 THICK
SPOKES:	Al 2024-T3 .030 THICK

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FIGURE 3

GRUMMAN WHEEL DESIGN

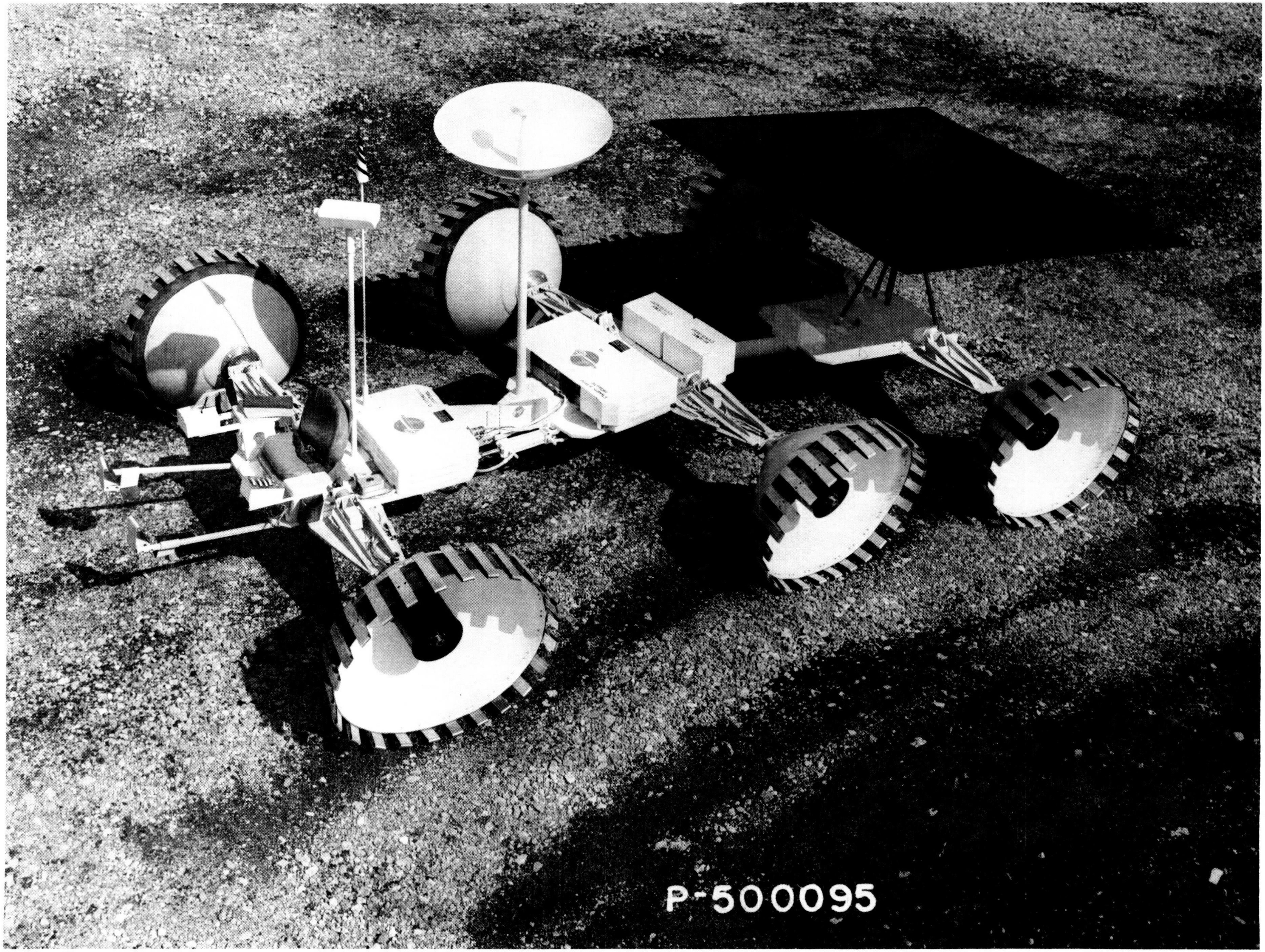

FIGURE 4

TABLE 1

DLRV WEIGHT SUMMARY (Lbs.)

ITEM	BENDIX		GRUMMAN	
Mobility		(341.6)		(299)
Drive	75		69	
Wheels	84.6		75	
Suspension	65		30	
Chassis	65		77	
Controller	34		30	
Steering	14		18	
Crew Systems		(40)		(39)
Electrical Power System		(181)		(176)
RTG	40		35	
Batteries	116		39	
Solar Array	---		49	
Distribution	---		38	
Power Conditioning	25		15	
Astrionics		(104.9)		(127)
Navigation	27.7		14	
Communication	43.9		69	
Remote Control	10		24	
Hazard Detection	23.3		20	
Thermal Control		-*-		(31)
Tiedown and Unloading		(30)		(28)
		697.5		700

*Thermal Control weight estimates included in each individual subsystem.

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TABLE 2

DLRV PERFORMANCE

Category	Requirement	Bendix	Grumman
Static Stability			
Pitch	>45°	46°	45°
Roll	>45°	50°	57°
Step Obstacle			
Manned	>39.4" (1 meter)	43"	46"
Unmanned	>11.8" (30 cm)	15"	46"
Crevasse			
Manned	>27.5" (70 cm)	27.6"	TBD
Unmanned			
1 Wheel	>27.5" (70 cm)	76"	TBD
2 Wheels	>39.4" (1 meter)	70"	TBD
Slope			
Manned	>35°	30°	TBD
Unmanned	>35°	24°	TBD
Break Angle			
Manned			
Lateral	<35°	31°	20°
Longitude	<35°	27.5°	27°
Unmanned			
Lateral	<35°	$\boxed{44^\circ}$	TBD
Longitude	<35°	$\boxed{45^\circ}$	TBD
Turn Radius	< 1 Veh. Length (Bendix 148") (Grumman 230")	$\boxed{152"}$	195"

TBD: To be determined.

□: Does not meet SOW requirement.